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Number of Solaria Needed to Predict Weed Seedlings in Two Summer Crops

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The utility of solaria (1 by 1-m plastic sheets) to predict densities of a few weed species in summer crops has been demonstrated previously, but needed further research to be adopted by farmers and advisors. We tested the method to detect important weeds in Argentina and Minnesota, and determined the minimum number of solaria required to predict the presence of emerged weed seedlings in the forthcoming growing season. Three experiments were performed in Buenos Aires Province, Argentina, and one in Minnesota. Solaria were placed in fields with different previous crops and soil management: no tillage (two fields) and conventional tillage (two fields). Preceding crops were corn (one field), wheat (one field), and double-cropped wheat/soybean (two fields). After weeds were enumerated, solaria were removed, sunflower (one field) and soybean (three fields) were planted, and weeds later assessed in each crop. Results indicate that one solarium per 1.9 ha can detect common lambsquarters with 95% confidence within the next summer crop. For other species, one solarium per 4.2, 1.2, 1.0, and 1.8 to 2.7 ha (depending upon field site) for large crabgrass, prostrate knotweed, wild buckwheat, and green foxtail, respectively, was required. The low cost and simplicity of assessment make this technique more suitable than that of soil seed-bank samples to predict weed emergence. The number of solaria required to forecast weed infestation levels confidently is sufficiently low that their use may be justified, especially in small fields of high-value crops.

Nomenclature: Common lambsquarters, *Chenopodium album* L. CHEAL; green foxtail, *Setaria viridis* (L.) Beauv. SETVI; large crabgrass, *Digitaria sanguinalis* (L.) Scop. DIGSA; prostrate knotweed, *Polygonum aviculare* L. POLAV; wild buckwheat, *Polygonum convolvulus* L. POLCO; corn, *Zea mays* L.; soybean, *Glycine max* (L.) Merr.; sunflower, *Helianthus annus* L.; wheat, *Triticum aestivum* L.

Key words: Bioeconomic models, site-specific weed management, weed control, weed seedling prediction, weed thresholds.

La utilidad del uso de las solaria (láminas de plástico de 1 por 1m), para predecir las densidades de algunas especies de maleza en cultivos de verano ha sido demostrada previamente, pero se requiere más investigación para que esta práctica sea adoptada por los agricultores y sus asesores. Evaluamos el método para detectar malezas importantes en Argentina y Minnesota EE UU y determinamos el número mínimo de solaria requerido para predecir la presencia de plántulas emergidas de malezas en la temporada productiva siguiente. Se llevaron a cabo tres experimentos en la Provincia de Buenos Aires, Argentina y uno en Minnesota. Las solaria fueron colocadas en lotes que difirieron en sus cultivos y sistemas de manejo de suelo previos, a saber: cero labranza en dos lotes y labranza convencional en otros dos. Los cultivos precedentes fueron: maíz (un lote), trigo (un lote), y doble-cultivo trigo/soja (dos lotes). Después que las malezas fueron enumeradas y las solaria fueron removidas, se sembró girasol (un lote) y soja (tres lotes) y posteriormente las malezas fueron valoradas en cada cultivo. Los resultados indican que un solarium por cada 1.9 ha, puede detectar *Chenopodium album* con 95% de confiabilidad en el cultivo del verano siguiente. Para otras especies se requirió un solarium por cada 4.2, 1.2, 1.0, y 1.8 a 2.7 ha (dependiendo de lote), para *Digitaria sanguinalis, Polygonum aviculare*, *Polygonum convolvulus y Setaria viridis* respectivamente. El bajo costo y la facilidad de la evaluación hacen que esta técnica sea más adecuada que la toma de muestras del banco de semillas para predecir la emergencia de malezas. El número de solaria requeridas para obtener pronósticos confiables sobre los niveles de infestación de malezas es suficientemente bajo para que su uso sea justificado, especialmente en lotes pequeños de cultivos de alto valor.

Because weeds compete with crops most intensely at early growth stages, effective PRE or early POST weed control is important to minimize weed interference, especially if losses greater than 10% are expected (Cousens 1998; Eyherabide and Cendoya 2002; Van Acker et al. 1993). Previous knowledge of which species and densities of weeds will compete with the crops is highly desirable. Such forecasting would increase the opportunities of managers to perform weed control actions at the right moment and with the best product, since application timing is essential to maximize economic benefits of weed control.

Farmers often make decisions about weed control after they or their advisors have surveyed fields and detected the weeds growing within the crop, at which time competition for light, water, and nutrients already may be occurring. To anticipate and facilitate decision making, some researchers have proposed and tested methods to predict the presence of weed seedlings in the field based on soil seed banks (Eyherabide et al. 2003; Forcella 1992; Wiles et al. 1992, 1995), and others have proposed and discussed methods for sampling weed seeds in the soil to determine weed distributions in fields (Cardina et al. 1997; Cardina and Sparrow 1996; Wiles 2005; Wiles and Schweizer 2002; Wyse-Pester et al. 2002; Zanin et al. 1998).

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Table 1. Location of experiments in Minnesota and Argentina (Arg).

Place	Nearest city	Tillage/country	Location
Swan Lake	Morris	Conv[a] (United States)	95°48′08″W, 45°41′52″N
Cinco Cerros	Balcarce	No-till (Arg)	58°22′69″W, 37°74′13″S
La Rinconada	Balcarce	No-till (Arg)	58°43′05″W, 37°94′91″S
San Francisco de Bellocq	Tres Arroyos	Conv (Arg)	59°53′06″W; 38°45′83″S

[a] Abbreviations: Conv, mechanical tillage before planting; no-till, no tillage.

Prediction based on counting weed seeds in soil samples has not been accepted by farmers or crop advisors, probably because the value of the knowledge is lower than the high cost of collection, extraction, and analysis of the samples (Wiles 2005). Another important point is that the extraction of weed seeds does not provide information about how many of the seeds will germinate because it does not differentiate between dormant and nondormant seeds unless additional and expensive analyses are performed.

Because the concept of forecasting weed populations seemed logical but its implementation too costly, Eyherabide et al. (2004) and Calviño and Eyherabide (2006) conceived an alternative method. They used small solaria (simple plastic sheets placed on the soil surface in early spring), based on the principle of solarization but used in temperate areas, to predict the possible number of weed seedlings of species such as common lambsquarters, green foxtail, large crabgrass, wild marigold (*Tagetes minuta* L.), and greater ammi (*Ammi majus* L.) within fields of summer crops in Minnesota and Buenos Aires Province, Argentina. Solaria offered a rational alternative to seed banks to predict future weed seedling populations because only the nondormant seeds in the seed bank germinated under the plastic sheets, and because most overwinter seed death and predation already had occurred. Additionally, Eyherabide et al. (2004) found that the same method of prediction could be useful to generate information as input for bioeconomic models (Wiles et al. 1996), at least when used in small areas. Nevertheless, this method of prediction has not been sufficiently tested to determine the minimum number of solaria required per unit area or per field for particular species.

The objectives of the research reported herein were (a) to confirm the utility of solaria to predict in-crop weed seedling presence, (b) to test if the method is useful to predict additional weed species presence, and (c) to determine the minimum number of solaria required in fields under different management practices for reliable prediction of weed presence in the field.

Materials and Methods

Site Description. Four experiments were performed during the growing seasons of 2003/04 and 2004/05 in Argentina (near Balcarce and Tres Arroyos) and in 2004 near Morris, Minnesota (Table 1). The soil types at each location were as follows: Swan Lake Research Farm near Morris: Barnes loam (Typic Udic Haploboroll), 4.1% organic matter (OM), pH 7.5; Cinco Cerros: Balcarce loam (Petrocalcic Paleudoll), 5.8% OM, pH 6, and Mar del Plata loam (Typic Argiudoll), 5.7% OM, pH 5.9; La Rinconada: Tres Esquinas clay loam (Typic Argiudoll), 5.2% OM, pH 6.7, and Mar del Plata loam; and San Francisco de Bellocq: La Otomana loam (Petrocalcic Hapludoll), 3.2% OM, pH 7.3, and Orense sandy loam (Petrocalcic Hapludoll), 2.7% OM, pH 7.2.

Placement of Solaria. General methods used in the four experiments consisted of locating solaria as described by Eyherabide et al. (2003). Each solarium was 1 by 1 m, and comprised of 100-µm-thick clear plastic tarp. In Argentina, sites were sprayed with glyphosate at 1.2 kg ae ha^{-1} prior to placement of solaria to eliminate any emerged weeds. All solaria locations were recorded with GPS[1] to facilitate subsequent in-crop counting of weeds as close as possible to the original site. If soil was not sufficiently moist for seed germination, the soil was irrigated with 20 L of water, and then solaria reset. Evaluation of number of weed seedlings under solaria was performed prior to planting in the case of no tillage (no-till) and before the last soil disturbance prior to planting under conventional tillage.

In each evaluation, all weed seedlings found under each solarium were counted and removed. No PPI or PRE weed control actions were performed in the crops before data were collected. To conduct weed seedling counts within the crops, sites from which solaria had been removed were relocated with the use of the GPS coordinates. Table 2 shows details of activities for each experimental site. Counting within the crops was done when weed infestations had reached thresholds and new weed emergence was not expected, varying from 29 d from planting at Swan Lake through 52 d at La Rinconada.

Experiment at Swan Lake, Minnesota. Sixteen solaria were randomly set within an area of 60 by 45 m. Location, dates of counting, etc. are shown in Tables 1 and 2. The previous crop was corn. Soybean was sown in rows 76 cm apart in a conventional-tillage system (moldboard plow in autumn, field

Table 2. Dates (month, day, year) of activities in each experiment. Values in parentheses indicate number of days between initial placement of solaria and the specified activity.

	Swan Lake	Cinco Cerros	La Rinconada	San Francisco
Number of solaria	16	42	40	40
Initial placement of solaria	04/04/04 (0)	10/07/03 (0)	10/08/04 (0)	09/14/04 (0)
Last count under solaria and removal	05/04/04 (30)	10/25/03 (18)	10/31/04 (23)	10/28/04 (32)
Date of planting	05/18/04 (44)	10/28/03 (21)	11/01/04 (24)	10/29/04 (33)
Counting within crop	12/19/03 (73)	06/15/04 (72)	12/12/04 (76)	12/10/04 (76)

Figure 1. Solaria distribution at Cinco Cerros, Argentina.

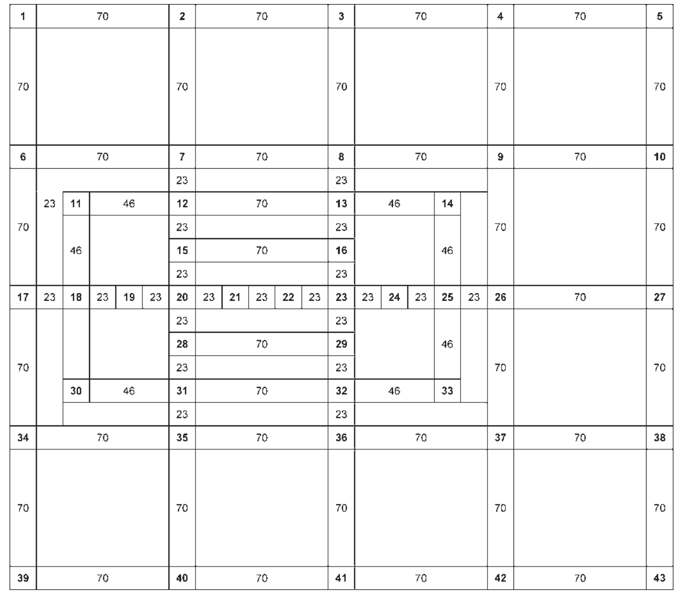

Figure 2. Distribution pattern of solaria in La Rinconada and San Francisco de Bellocq, Argentina. Each bold number in a cell identifies a solarium, and normal numbers indicate distance between two solaria in the line.

cultivation in spring) at 500,000 seeds ha^{-1}. Weed seedlings were counted prior to planting and again at the V2 growth stage (two fully developed trifoliate leaves) of soybean.

Experiment in Cinco Cerros, Argentina. This experiment was performed in a 28-ha field in 2003/2004 in which the previous main crops (2002/2003) were wheat followed by soybean. Glyphosate at 1.2 kg ae ha^{-1} was sprayed broadcast as chemical fallow prior to locating 42 solaria. The field was divided in 29 zones of ca. 1.1 ha; at least one randomly placed solarium was located in each zone. The remaining 13 solaria were located at distances of at least 50 m from one another so that areas with low and high sampling densities occurred, as shown in Figure 1.

Soybean 'Asgrow 4422' was planted no-till in rows 52 cm apart at a density of 500,000 seeds ha^{-1}. Weeds were counted within the crop just before any POST herbicide application, when soybean was at the V4 growth stage. This counting was delayed because few weeds had appeared, and the adviser and farmer considered an earlier weed assessment as unnecessary (see Table 2).

Experiment in La Rinconada, Argentina. The previous main crop (2003/2004) in this field was wheat followed by soybean. In this experiment, the location of solaria followed the design shown in Figure 2. The distance from field fences to any side of the experiment was at least 100 m. Each side of the experimental area had five solaria, leaving 70 m between adjacent solaria, with some areas having zones with a higher solaria density. A total of 43 solaria were used. Irrigation was applied under each solarium (see above) to facilitate weed seed germination. Weeds were counted within the crop just before herbicide application when soybean was at the V2 stage of growth, before any POST herbicide application (Table 2). Low temperatures and soil moisture delayed the crop and weed growth, so in-crop counting of weeds was performed some days later.

Experiment in San Francisco de Bellocq, Argentina. The previous crop in this field was wheat, and solaria were placed before planting sunflower 'Nidera CL 101' under conventional tillage (disked twice and harrowed). Solaria were placed following the same design as in La Rinconada (Figure 2), and weed seedling counting within the crop was performed when sunflower had two true leaves, which was before POST application of imazapyr (Table 2).

Statistical Analyses. The agreement between recommendation based on solaria weeds counts and recommendation based on in-crop weed counts was measured through the coefficient K as defined by Cohen (1960). This coefficient gives a statistical measure of agreement between two methods of decision, corrected by the agreement that could be found by chance. It ranges between zero and one, where one means perfect agreement for both methods, and zero means that there is no more agreement than that expected by chance. The estimation of this coefficient is based on a contingency table (Table 3) as proposed by Eyherabide et al. (2003).

To evaluate agreement between methods to decide control for a single species, the number of weed seedlings found under solaria and within the crop were considered. Weed seedling threshold densities (number m^{-2}) of large crabgrass, green

Table 3. Table of contingencies used to determine the need for weed control.[a]

	CWD		
SWD	< TWDf [c]	≥ TWDf	
< TWDs	N_{11} Number of solaria where control was not needed nor recommended	N_{12} Number of solaria where control was needed, but not recommended	Total $N_{1\cdot}$
≥ TWDs	N_{21} Number of solaria where control was not needed, but recommended	N_{22} Number of solaria where control was needed and recommended	$N_{2\cdot}$
Total	$N_{\cdot 1}$	$N_{\cdot 2}$	$N_{\cdot\cdot}$

[a] Abbreviations: CWD, in-crop weed density; [b] SWD, solaria weed density; TWD, threshold weed density: s = in solaria, f = within crop.

Table 4. Threshold weed densities according to data observed under solaria or within the crop.

Weed	Under solaria	Within crop
	Number m^{-2}	
Large crabgrass	7	6
Foxtail spp.	7	14
Common lambsquarters	1	1
Wild buckwheat	8	6
Prostrate knotweed	1	3
Eastern black nightshade	1	1

foxtail, bristly foxtail [*Setaria verticillata* (L.) Beauv.], and common lambsquarters, were taken from results published previously and discussed by Eyherabide et al. (2003) and Calviño and Eyherabide (2006). For wild buckwheat and prostrate knotweed, the critical densities were established according to an inquiry of 10 qualified advisors and researchers in weed science in Balcarce. For eastern black nightshade (*Solanum ptycanthum* Dun.), just 1 plant m^{-2} was enough to elicit control recommendations because of the serious downgrading of seed quality that occurs when nightshade fruit stains harvested soybean seeds. For some weed species, solaria overestimates or underestimates the number of weeds that will emerge within the crops (Eyherabide et al. 2003); therefore, the threshold used under solaria was different than the within-crop values (Table 4).

K was estimated as the following (see also Table 3):

$$\hat{K} = [N_{\bullet\bullet}(N_{11} + N_{22}) - N_{\bullet 1}N_{1\bullet} - N_{\bullet 2}N_{2\bullet}] / \left(N_{\bullet\bullet}^2 - N_{\bullet 1}N_{1\bullet} - N_{\bullet 2}N_{2\bullet}\right)$$

The hypothesis of independence, or no more agreement than expected by chance ($K = 0$), was tested ($\alpha = 0.05$) based on the asymptotic normal distribution of $\hat{K}$ (Bishop et al. 1975).

To determine the minimal number of solaria in each field to predict the presence of weed seedlings within the crop, several random samples of solaria were taken into account to make the decision; for each sample size, the proportion of right decisions was evaluated. To perform this analysis, each weed must be present at some solaria in densities above the chosen threshold, and below in others. The relationship between sample size (measured as number of solaria per ha used) and the proportion of right decisions was modeled by a smooth spline function and used to determine the number of solaria that could provide a 0.95 probability of making the right decision. For a sample size of 1, there were only 43 possible samples from which to choose, and all of them were evaluated. For a sample size of 2, there were 903 different combinations, and all of them were evaluated. However, for sample sizes between 3 and 25, there were more than 10,000 possible combinations; therefore only 1,000 of them were selected randomly to evaluate the proportion of right decisions. All statistical analyses were performed with R 2.9.1 software (R Development Core Team 2009).

Results and Discussion

Weed Emergence. Table 5 presents the densities of the major weeds recorded within the crops in the four experiments. More late weeds (large crabgrass and foxtail spp.) occurred in La Rinconada and San Francisco than in Cinco Cerros and Swan Lake. Information obtained for Cinco Cerros and Swan Lake indicated effective weed management in previous years; no records for La Rinconada and San Francisco were available. The influence of weed control in previous crops and during fallow on the amount of weeds in following years has been demonstrated by Schweizer and Zimdahl (1984), Calviño and Eyherabide (2006), and others. The large standard deviations (SD), equal to or twice that of the mean, showed that the weed densities under solaria or within the crop in each field were heterogeneous, similar to data from Cardina et al. (1995), Forcella et al. (1992), Wiles and Schweizer (2002), and Wyse-Pester et al. (2002). Considering the average density of weed seedlings in crops, control thresholds proposed in Table 5 were reached by the following species and sites: foxtail spp. at Swan Lake, La Rinconada, and San Francisco; large crabgrass at La Rinconada and San Francisco; common lambsquarters at Swan Lake and San Francisco; prostrate knotweed at La Rinconada and San Francisco; wild buckwheat at La Rinconada; and eastern black nightshade at Swan Lake. Only at these sites and for those specific weeds was control considered necessary.

Utility of Solaria to Predict the Need for Weed Control. Percentages of accordance and K indices for each weed in all

Table 5. Mean and standard deviation (SD) of weed seedling densities under solaria and within the crops.

	Location															
	Cinco Cerros				Swan Lake				La Rinconada				San Francisco			
	Solaria		In-crop		Solaria		In-crop		Solaria		In-crop		Solaria		In-crop	
Weed species	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
	Seedlings m^{-2}															
Large crabgrass	3.7	4.2	4.8	6	–	–	–	–	614	695	1050	498	480	386	912	656
Foxtail spp.[a]	1.2	2.5	0.91	1.7	16	13	22	19	217	413	83	120	43	58	71	135
Common lambsquarters	0.1	0.2	0.3	0.7	11	13	11	10	0.5	1.5	8.8	41	9	24	54	121
Wild buckwheat	0.5	1.2	1.3	1.9	–	–	–	–	11	14	13	18	0.3	1.5	3	14
Prostrate knotweed	–	–	–	–	–	–	–	–	2	12	7.8	21	16	37	17	26
E. black nightshade	–	–	–	–	9	13	6	9	–	–	–	–	–		–	–

[a] Mixture of green and bristly foxtail in Argentina, and green foxtail and yellow foxtail [*S. glauca* (L.) Beauv.] in the United States.

Table 6. $\hat{K}$ estimated index of agreement between solaria-based decisions and in-crop based decisions and percent of solaria agreements and disagreements for control. Data are presented for each weed species, combined across experimental sites. Column designations: B, agreement, control needed and recommended; C, agreement, control not needed and not recommended; D, total agreements; E, disagreement, control not needed but recommended; F, disagreement, control needed but not recommended; G, total disagreements.

Weed species	$\hat{K}$ index	B	C	D	E	F	G
Large crabgrass	0.68*	69	19	88	3	9	12
Foxtail spp.	0.63*	43	39	82	11	8	19
Common lambsquarters	0.37*	27	40	67	5	28	33
Wild buckwheat	0.50*	11	73	84	7	8	15
Prostrate knotweed	0.42*	29	42	71	8	21	29
Eastern black nightshade	0.20 (NS)	69	6	75	6	19	25

[a] The asterisks denote significant degree of agreement at $\alpha = 0.05$.

fields are shown in Table 6. The null hypothesis, i.e., no agreement, was rejected at $\alpha = 0.05$ for all weeds except for eastern black nightshade. For large crabgrass, foxtail (mix of three species), and wild buckwheat, agreements totaled over 80% between control decisions based on solaria and in-crop weed counts (Table 6, columns B–D). If a "good decision" included disagreement between solaria advice for no control when control actually is needed (because that mistake can be rectified by POST spraying), then good decisions reached values between 90 and 97% (Table 6, columns D + F). Assuming the same interpretation as above for good decisions, for common lambsquarters, accordances rise from 67 to 95%, whereas those for prostrate knotweed climbed from 71 to 92%. These results agree with those found by Eyherabide et al. (2003) and Calviño and Eyherabide (2006) for large crabgrass, foxtail spp., and common lambsquarters as major weeds in soybean, corn, and sunflower. The case for eastern black nightshade was different, where *K* was not significant; nevertheless, analogous values to those listed above were 75 and 94%, respectively.

Solaria Densities for Reliable Predictions about Weed Control. Necessary conditions to perform this analysis were met for large crabgrass at Cinco Cerros, foxtail spp. at La Rinconada and San Francisco, wild buckwheat at la Rinconada, prostrate knotweed at San Francisco, and common lambsquarters at San Francisco. Figures 3a–f show proportions of correct decisions according to the number of solaria and optimum density of solaria to make a right decision about control with 95% confidence.

For common lambsquarters in San Francisco, an adjusted smooth spline function determined that 52 solaria per 100 ha should be enough to make decisions about control. For prostrate knotweed and foxtail spp. in the same field, 84 and 45 solaria were needed for every 100 ha, respectively. For large crabgrass at Cinco Cerros, only 24 solaria for every 100 ha were needed. For wild buckwheat at La Rinconada, 98 solaria were sufficient, but only 37 solaria were suggested to predict the need to control foxtail spp. Because not all weeds need the same number of solaria per area unit to be detected, perhaps the highest density of solaria would be advised, which in the present case corresponds to those needed for wild buckwheat (equated to about 1 solarium per ha). However, the effects of species like wild buckwheat on summer crops also must be considered.

Even though wild buckwheat and prostrate knotweed are common in winter cereal crops and are considered as "early" weeds, they also compete with summer crops, and were predicted by solaria at La Rinconada and San Francisco. These weeds needed the highest number of solaria to be detected. Interestingly, neither had been detected by solaria in previous experiments with summer crops, and using these species as indices for required solaria densities may not be justified. The case of common lambsquarters is different. The number of solaria needed to detect this weed is about 50% lower than that needed for prostrate knotweed or wild buckwheat. However, because even very low seedling densities require it to be controlled because of its competitive ability, perhaps it should be considered a keystone species and used to determine solaria densities. Additional studies will be needed to assess this possibility.

The aim of using solaria is to determine in advance if the presence of a number of weeds in crops will be enough to justify the need for weed control, and thereby minimize competition of weeds with the crop and soil seed-bank enrichment from plants not controlled. The considerable body of knowledge regarding the use of seed banks as an information resource for making management decisions

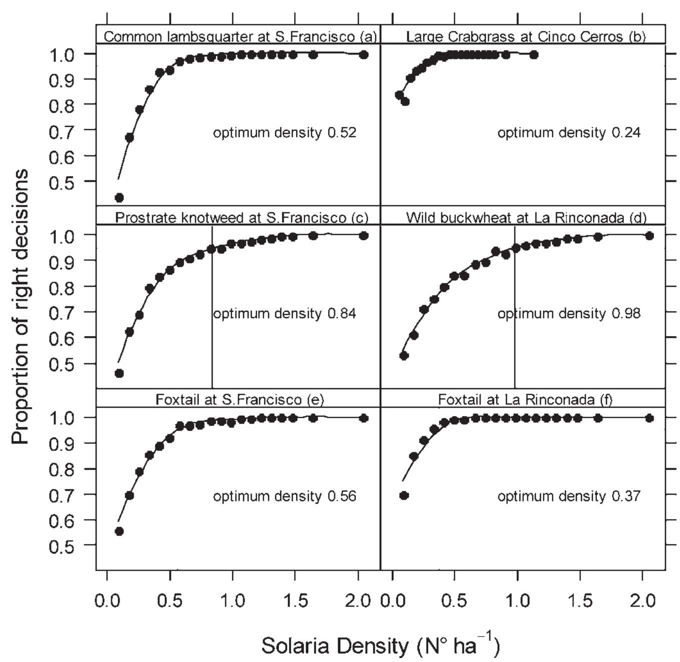

Figure 3. Proportion of right decisions according to the number of solaria.

(Buhler 1999, Cardina et al. 1995, 1997; Cardina and Sparrow 1996, Cousens et al. 2002, Forcella 1992, Forcella et al. 1992, Gerhards et al. 1997, Gold et al. 1996, Schweizer and Zimdahl 1984, Swinton 2005, Wyse-Pester et al. 2002, Zanin et al. 1998, among many others) has not been adopted by farmers or advisors, likely for many and varied reasons such as time and labor constraints, cost of analysis, etc. (Wiles 2005). With solaria, however, a first approximation for the need to exert PRE or early POST control can be pursued and achieved with relatively little effort, as evaluations of species' abundances above or below predetermined thresholds are simple. The real advantages of the system are the anticipated knowledge of which species will potentially compete with the crop, the low cost of the activity, the possibility to combine solaria with other methods that could predict the timing of weed emergence (Spokas and Forcella 2009), and the large sampling area (i.e., about 1 m^2 is being viewed compared to considerably smaller aggregate areas sampled by soil probes for seed bank analyses). The requirement for small, clear plastic sheets makes this technique suitable for use by farmers and/or their advisors. Because they are cheap and simple to assess, many more solaria can be located in a field than that recommended for samples of soil seed banks.

Sources of Materials

[1] GPS equipment included an eTrex Vista, Garmin International, Inc. unit in Argentina, and a Trimble Ag-132 unit in the United States.

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Literature Cited

Bishop, Y. M., S. E. Feinberg, and P. W. Holland. 1975. Discrete Multivariate Analysis. Theory and Practice. Cambridge, MA: MIT. 557 p.

Buhler, D. D. 1999. Expanding the context of weed management. J. Crop Prod. 2:1–7.

Calviño, P. and J. J. Eyherabide. 2006. Use of solaria to predict weed density and floristic composition in no-till cropping systems. Pesq. Agrop. Bras. 41: 409–413.

Cardina, J., A. G. Johnson, and D. H. Sparrow. 1997. The nature and consequence of weed spatial distribution. Weed Sci. 45:364–373.

Cardina, J. and D. Sparrow. 1996. A comparison of methods to predict weed seedling populations from the soil seed bank. Weed Sci. 44:46–51.

Cardina, J., D. H. Sparrow, and E. L. McCoy. 1995. Analysis of spatial distribution of common lambsquarters (*Chenopodium album*) in no till soybeans (*Glycine max*). Weed Sci. 43:258–268.

Cohen, J. 1960. A coefficient of agreement for nominal scales. Educ. Psych. Meas. 20:37–46.

Cousens, R. 1998. Misinterpretations of results in weed research through inappropriate use of statistics. Weed Res. 28:282–289.

Cousens, R. D., R. W. Brown, A. B. McBratney, B. Whelan, and M. Moerkerk. 2002. Sampling strategy is important for producing weed maps: a case study using kriging. Weed Sci. 50:542–546.

Eyherabide, J. J., P. Calviño, F. Forcella, M. G. Cendoya, and K. E. Oskoui. 2003. Solaria help predict in-crop weed densities. Weed Technol. 17:166–172.

Eyherabide, J. J. and M. G. Cendoya. 2002. Critical periods of weed control in soybean for full field and in-furrow interference. Weed Sci. 50:162–166.

Eyherabide, J., D. Peterson, and F. Forcella. 2004. Solaria provide pre plant information on weed densities, distributions and management. Proc. North Cent. Weed Sci. Soc. 59:52.

Forcella, F. 1992. Prediction of weed seedling densities from buried seed reserves. Weed Res. 32:29–38.

Forcella, F., R. G. Wilson, K. A. Renner, J. Dekker, R. G. Harvey, D. A. Alm, D. D. Buhler, and J. Cardina. 1992. Weed seedbanks of the U.S. corn belt: magnitude, variation, emergence, and application. Weed Sci. 40:636–644.

Gerhards, R., D. Y. Wyse-Pester, D. A. Mortensen, and G. Johnson. 1997. Characterizing spatial stability of weed populations using interpolated maps. Weed Sci. 45:108–119.

Gold, H. J., J. Bay, and G. G. Wilkerson. 1996. Scouting for weeds, based on the negative binomial distribution. Weed Sci. 44:504–510.

R Development Core Team. 2009. R: A language and environment for statistical computing. R Foundation for Statistical Computing: Vienna, Austria: R Foundation for Statistical Computing. http://www.R-project.org.

Schweizer, E. E. and R. L. Zimdahl. 1984. Weed seed decline in irrigated soil after six years of continuous corn (*Zea mays*) and herbicides. Weed Sci. 32:76–83.

Spokas, K. and F. Forcella. 2009. Software tools for weed seed germination modeling. Weed Sci. 57:216–227.

Swinton, S. M. 2005. Economics of site–specific weed management. Weed Sci. 53:259–263.

Van Acker, R., C. J. Swanton, and S. F. Weise. 1993. The critical period of weed control in soybean (*Glyicine max*). Weed Sci. 41:194–200.

Wiles, L. J. 2005. Sampling to make maps for site-specific weed management. Weed Sci. 53:228–235.

Wiles, L. J., D. H. Barlin, E. E. Schweizer, H. R. Duke, and D. E. Whitt. 1995. A new soil sampler and elutriator for collecting and extracting weed seeds from soil. Weed Technol. 10:35–41.

Wiles, L. J., R. P. King, E. E. Schweizer, D. W. Lybecker, and S. M. Swinton. 1996. GWM: general weed management. Model. Agric. Syst. 50:355–376.

Wiles, L. J. and E. E. Schweizer. 2002. Spatial dependence of weed seed banks and strategies for sampling. Weed Sci. 50:595–606.

Wiles, L. J., G. G. Wilkerson, H. J. Gold, and H. D. Coble. 1992. Modeling weed distribution for improved postemergence control decision. Weed Sci. 40:546–553.

Wyse-Pester, D. Y., L. J. Wiles, and P. Westra. 2002. Infestation and spatial dependence of weed seedling and mature weed populations in corn. Weed Sci. 50:54–63.

Zanin, G., A. Berti, and L. Riello. 1998. Incorporation of spatial variability into the weed control decision process. Weed Res. 38:107–118.

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